UNCLASSIFIED

AD 401 214

Reproduced
by the

DEFENSE DOCUMENTATION CENTER

FOR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION, ALEXANDRIA, VIRGINIA

UNCLASSIFIED

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

AD No. 401214
ASTIA FILE COPY
401 214

63-3-2

INTERIM TECHNICAL REPORT

on the

RESEARCH, DEVELOPMENT, AND FABRICATION OF TUNNEL EMISSION CATHODES

Contract No. DA-49-186-502-ORD-1053

FIRST QUARTERLY REPORT

Covering the period July through September, 1962

For

DIAMOND ORDNANCE FUZE LABORATORIES

WASHINGTON, D. C.

ASTIA
APR 15 1963
TISIA A

RECEIVING TUBE DEPARTMENT

GENERAL ELECTRIC

OWENSBORO, KENTUCKY

$1.60

(5) 353 500

INTERIM TECHNICAL REPORT

on the

(8) RESEARCH, DEVELOPMENT, AND FABRICATION OF TUNNEL EMISSION CATHODES

(12) Contract No. DA-49-186-502-ORD-1053

(17) ~~FIRST~~ QUARTERLY REPORT, no. 1,
~~Covering the period~~ July through September, 1962

(9) Sep 62
(10) 19p. incl illus-
7 refs.
(11) N. A.
(13) N.A

For

DIAMOND ORDNANCE FUZE LABORATORIES
WASHINGTON, D. C.

Prepared: (6) C. E. Horton
J. W. Hall, II

Approved: A. P. Haase

Receiving Tube Department
General Electric
Owensboro, Kentucky

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

PURPOSE

The objectives ~~of the work being performed under this contract~~ are to develop a better theoretical understanding of the tunnel cathode, to evaluate both materials and processes for the fabrication of this type of device, and thereby to develop a tunnel cathode having desirable electrical and mechanical characteristics.

Cont'd on p. v

~~Work is concerned with getting a better theoretical understanding of tunnel cathodes and evaluation of materials and processes for the fabrication of these devices.~~

Cont'd from p. iv

ABSTRACT

The work ~~done during the first quarter has been~~ this period was directed largely toward improving the quality of the anodized aluminum oxide film through which electron tunneling occurs. Because the properties of this film appear to be very sensitive to the conditions under which the aluminum emitter film is prepared, considerable effort has gone into improving the vacuum level and cleanliness during the vacuum deposition of this film. A large improvement in the insulating film current density ~~has been~~ was made as a result of processing changes.

MEETINGS AND CONFERENCES

1. Discussion of contract and status of tunnel cathode work with H. G. Chandler at Owensboro, July 31 - August 2, 1962.
2. Review of project and objectives with DOFL and NASA personnel at DOFL, September 15, 1962. C. E. Horton, J. R. Crittenden, and H. W. Lupton in attendence from General Electric.
3. Discussion with H. G. Chandler at Owensboro, September 11, 1962.
4. Discussion of replicating techniques for electron microscope study of glass and metal film surfaces, with General Electric Research Laboratory and General Engineering Laboratory personnel at Schenectady, New York, by T. J. Nall, October 18-19, 1962.

BRIEF DESCRIPTION OF TUNNEL CATHODES

The operation of tunnel cathodes has been described in some detail in the literature, [1,2] but will be described here very briefly using the energy level diagram of Figure 1. This shows a metal layer, a thin insulating film, a thin metal film, and a vacuum. The thickness of the insulating film and the thin metal film are of the order of 100Å. The thin metal film is made about five volts positive with respect to the metal layer on the left. Electrons from the metal on the left are able to pass through the insulating film by a process that involves tunneling and also conduction through the insulator conduction band. Electrons may also pass through the insulator by Schottky emission into the insulator conduction band.[3] During the passage through the insulator, the electrons receive an amount of energy corresponding to the voltage applied to the thin metal film. Those that do not dissipate their energy within the insulating film or the thin metal film will have enough kinetic energy to overcome the work function barrier of approximately four electron volts that exists between the metal and the vacuum. The dashed horizontal line indicates the energy diagram for one such electron as it passes through the cathode and into the vacuum. These electrons are thus emitted into the vacuum, and the device is therefore a cathode.

Because the current densities theoretically obtainable in such a device are quite large, the limitations on the performance of tunnel cathodes will probably be determined by practical considerations such as choice of material, the quality and uniformity of the thin films, etc.

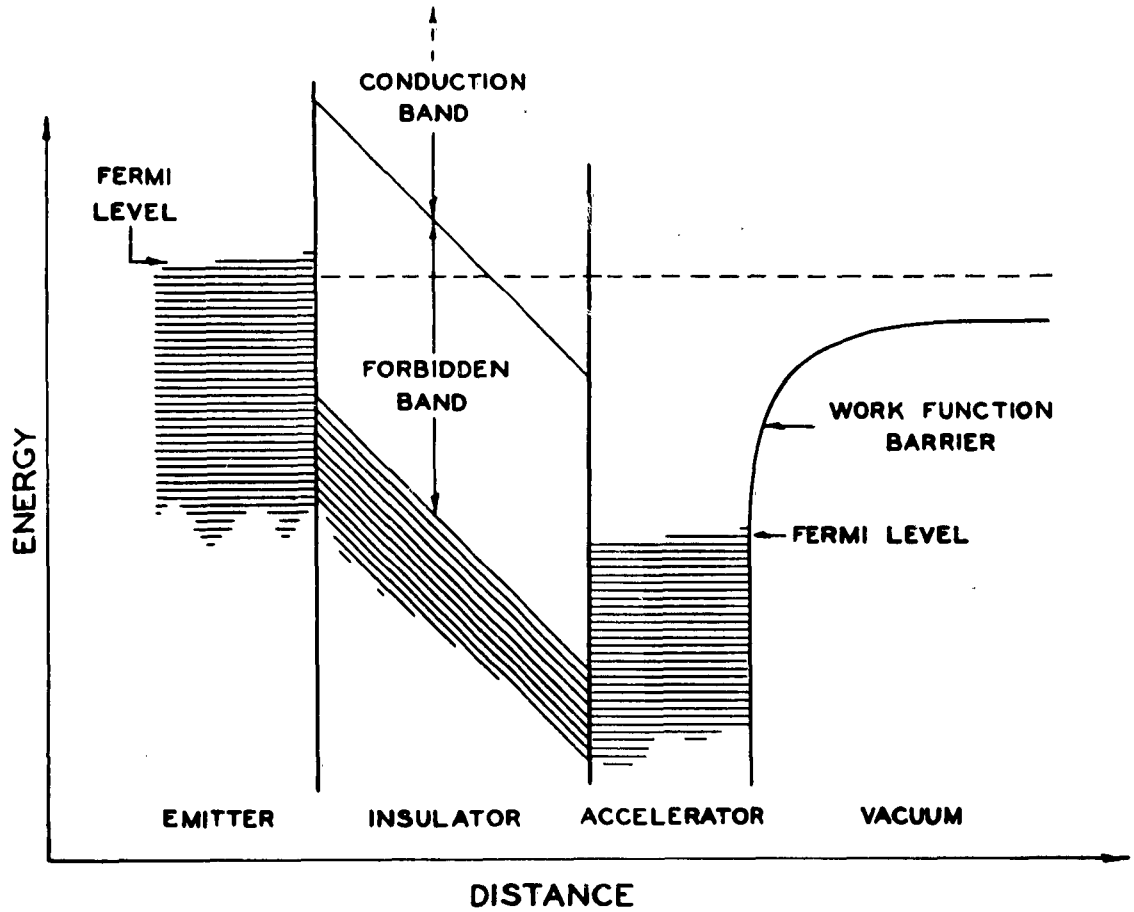
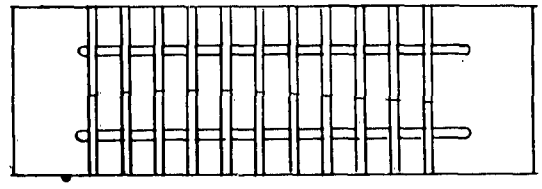


FIG. 1 ENERGY DIAGRAM OF TUNNEL CATHODE

DESCRIPTION OF TEST SAMPLES

The tunnel cathode test units now being studied use crossed metal films on microscope slide substrates. Figure 2 shows the geometrical arrangement of the films. The long stripes are the emitter layers and are deposited first. The deposition process is vacuum evaporation of metal. The insulating film is then formed. Currently, the emitter layers are aluminum, and the insulating film is formed from the aluminum by anodization. The accelerators, the vertical metal strips indicated in Figure 2, are deposited last. These have been aluminum in most of the units made, but gold has also been used.

A scribe line is made down the center of the slide to give electrical separation of the pairs of test units that are formed. To facilitate making electrical contact to the rather delicate thin films, a small amount of indium,



Test Units on Microscope Slide Substrate
Figure 2

used as a solder, is applied to the ends of the metal films.

The metal strips are all one millimeter wide. The eleven accelerator strips (for practical reasons, only ten of these are regularly used) are centered unsymmetrically on the slide. Consequently, if the slide is reversed end-for-end in the evaporation mask and another metal film is deposited, the new set of accelerator strips will fall midway between the first set. This permits, for instance, putting a set of gold accelerators plus a set of aluminum accelerators over a common insulating film for making a direct comparison of the two accelerator materials.

ELECTRICAL TEST METHODS

Two electrical test circuits, both built prior to the present contract, are currently used for evaluating the performance of tunnel cathode test units. Both methods use a dual-beam oscilloscope with calibrated deflection sensitivities (Tektronix type 502) to display the voltage-current characteristics of the unit under test. The dual-beam feature is used to permit simultaneous monitoring of both the total film current* and that portion of the film current that is emitted.

The simpler and more often used circuit uses a rectified 60-cycle voltage as the voltage applied to the sandwich and to the horizontal deflection circuit of the oscilloscope. The circuit in its present form is shown in Figure 3. A Variac and range switch vary the amplitude of the applied voltage. A monitoring resistor is used to measure the current flowing through the insulating film. In earlier measurements a d-c supply and second monitoring resistor were used for measuring emission current; however, the test setup as used during this quarter does not include this feature because the other test circuit is intended for all emission testing.

Rectification of the 60-cycle sweep voltage is desirable for two reasons. First, this reduces the tendency for damage to the test units resulting from heat generated in the testing process. Second, some combinations of film materials show considerably higher electrical breakdown characteristics in the forward direction than in the reverse direction; and allowing reverse current to flow may unnecessarily limit the range over which the units may be tested.

To enable high currents to be drawn without damaging the units thermally, a pulse test circuit essentially identical to that described by Mead[4] was constructed. The circuit diagram of this test set is shown in Figure 4. This circuit passes a single 15 microsecond pulse through the insulating film. During this pulse, the current rises linearly from zero to its final value. The voltage is therefore not set by the circuit, but is determined by the current and the E-I characteristic of the insulating film. This E-I characteristic is displayed on one beam of the oscilloscope, with current on the horizontal axis. The other beam shows emission current as a function of film current. The oscilloscope traces are bright enough that the single sweep can be recorded on Polaroid 3000 speed/type 47 film.

* The term "film current" is preferred over "tunneling current" because the latter excludes the possible contribution of Schottky emission to the current passing through the insulator.

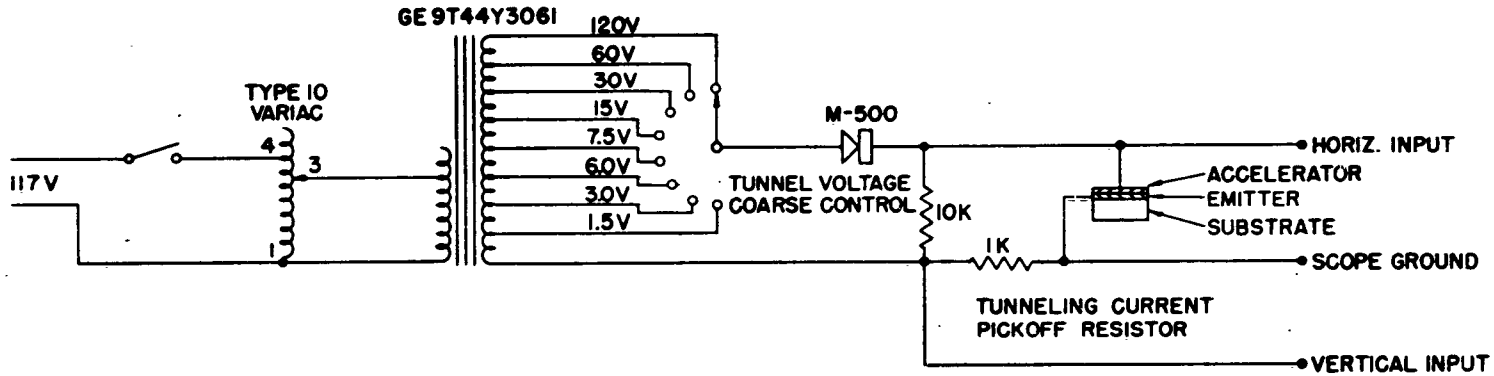


FIG. 3 FILM CURRENT TEST SET (60 CYCLE)

The scope trigger source is different from that used by Mead in his original circuit. To eliminate occasional multiple pulses, we used the smoothly-varying resistance of a momentarily-illuminated photoconductive cell to supply a single trigger pulse to the oscilloscope.

The 60 cycle test circuit is generally used when only film current is measured. When measurements of both film current and tunneling current are desired, the pulse test circuit is used. The reason for this is that the film current measurements are made in air (and occasionally with the test units immersed in liquid nitrogen), which seems to provide adequate cooling to enable factors other than thermal dissipation to determine the current-carrying capabilities of our present insulating films. Because of this, the 60 cycle test circuit provides a convenient means for comparative evaluation of different test lots immediately following their preparation. This method is also used to indicate those lots that should be prepared for emission testing.

The emission testing is of course done under vacuum; and the units are found to burn out at considerably lower values of film current, presumably because their ability to dissipate heat is substantially reduced. Pulse testing under these conditions is desirable in order to determine the maximum emission capabilities of the thin film cathodes.

Because of the difficulties encountered with insulating film quality, and our desire to control the tunneling layer characteristics before proceeding, no emission testing has been conducted during this quarter.

The method already developed for performing the emission test is to seal the thin film test units into a metal tube envelope with an octal base. Figure 5 is a drawing of the assembly as it appears before the metal tube envelope is put in place. The substrates are cut with a glass cutter into sections each containing six tunnel cathodes and mounted facing a common anode. A separate sealed-off unit is used to permit emission testing without interrupting the preparation of additional thin film units in the vacuum system, and the choice of a standard receiving tube envelope as the vacuum enclosure was made as a matter of convenience. The metal envelope has an advantage over the more common glass envelope because the final seal can be made without appreciably heating the inside of the tube. Early

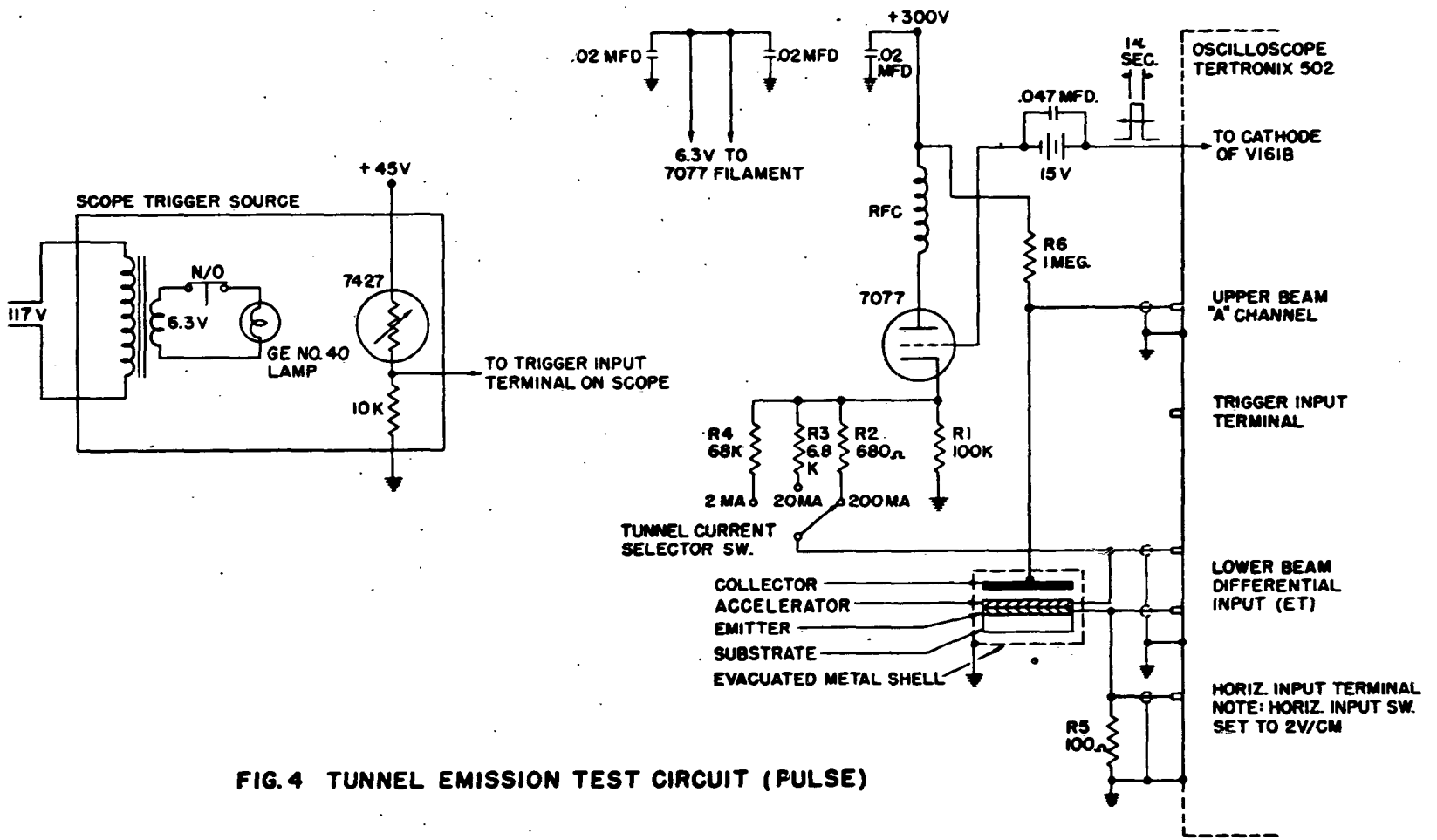
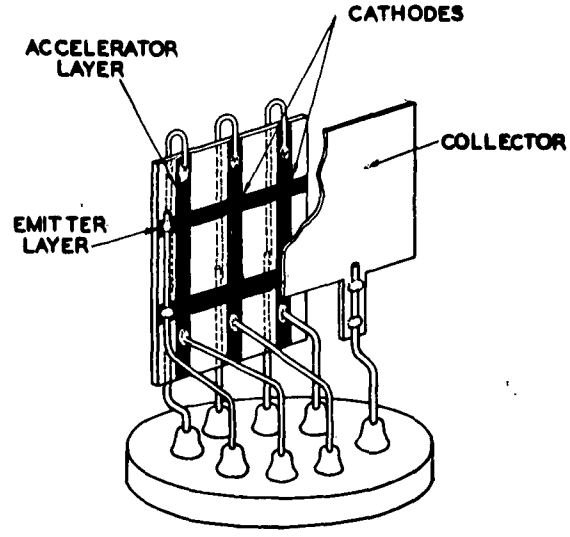


FIG. 4 TUNNEL EMISSION TEST CIRCUIT (PULSE)



Tunnel Cathodes Mounted On Octal Stem For Emission Test

Figure 5

attempts to use glass tube envelopes resulted consistently in damage to the type of units being made at that time. The temperature of the inside of the glass tube envelope during sealing was estimated to be about 400°C.

A further advantage of the low sealing temperature is that indium (melting point 155°C) may be used to make electrical connection between the test units on the microscope slide substrate and the tube pins. These soldered connections also serve very satisfactorily as a mechanical support for the substrate.

INVESTIGATION OF FILM QUALITY

A. Discussion

The electrical performance of a thin film tunnel cathode is obviously dependent on the quality of the films from which it is made. The project emphasis during this quarter has been on improving the quality of aluminum and aluminum oxide films.

Some of the factors that would be expected to affect the quality of these films are the chemical purity of the materials, the various gasses present in the vacuum system during deposition, substrate cleanliness and temperature, evaporation rate, the type of vapor source used, and, for insulating films, the method of preparation (for our present films, the anodizing schedule). It would be surprising to find ultimately that film quality is not affected by nearly all of these variables; however, in almost every case the experimental results strongly suggest that at present one factor - the vacuum level during film deposition - is by far the most significant variable if reasonable care is given the other various steps involved in the preparation of the films. Controlled experiments to find the effects of other variables have almost invariably been disappointing, and one can only conclude that these effects are overshadowed by the effects of some other variable, presumably the vacuum system pressure. Consequently, this report will present only very limited data on such experiments.

Indications of film quality may be measured in many ways: structural details such as porosity, crystalline structure, and density; surface structure and smoothness; electrical resistivity; and chemical purity. In the present investigation, the most convenient method has been to measure the film current characteristics. A good thin film sandwich will support a relatively high current; a poorer film will burn out more easily. Essentially, this measures the quality of the insulating film, which is probably the most critical component of the tunnel cathode. In most cases, burnout at a low current probably means non-uniformities in the insulating film. These may be either in the form of thin spots that carry a disproportionately large share of the total current or structually weak spots that break down and short out under the applied electrical stress. In either case, the difficulty appears to have its origin in the quality of the aluminum film from which the anodized oxide film is grown.

Because film current provides a simple monitor of film quality, other measurements of film properties (except for diagnostic purposes) have generally been postponed to the time when more consistent experimental results can be obtained. It is not felt that a more detailed study of film properties at this time would contribute much to the understanding of the factors that will eventually figure in the selection of materials and processes for the best possible cathode design.

B. Substrate

Although serving only as a mechanical support for the test units, the nature of the substrate is important in many ways. The smoothness of the films is dependent on the smoothness of the substrate. The way in which the film grows depends partly on the binding forces between the substrate molecules and the atoms of the evaporant. Substrate temperature affects the mobility of the evaporant atoms on the substrate surface and is a factor in determining the structure and smoothness of the film.

Microscope slides are currently used as substrates for our thin film tunnel cathodes. Electron microscope replicas indicate a surface appearance similar to that found by Lemke[5], probably smooth enough to permit a satisfactory film structure. Good adherance and continuity of the film appear to be possible with glass, provided only that the slide is completely oil free. As suggested by Swaine and Plumb,[6] somewhat better aluminum films appear to be obtained with a moderately heated substrate; but the existance of this effect has not definitely been proven by our own experimental results.

Two processes have been used to clean the substrates. In the first, the substrate is thoroughly washed in a hot Alconox solution and rinsed with distilled water. The slide is then rinsed in methanol and allowed to dry, after which it is again rinsed in distilled water.

The other method used involved the use of a high grade of MgO powder. With this method, a thick paste is made using distilled water and the MgO powder. The paste is rubbed over the surface of the slide using rubber gloves. The fine grains of the MgO in the paste act as an abrasive and polish the surface. During the polishing, the surface layer of the glass substrate is removed and a clean surface is obtained. The difficulty encountered using this process was that not all of the MgO was rinsed away. After drying, MgO films could be detected. We believe that this problem is a matter of technique that can be worked out by further experimentation with this cleaning method.

An additional pre-cleaning step has been found necessary with many of the slides. Under strong light, a very thin deposit resembling a thin mildew film is observed on some slides. We have been unable to remove this deposit with conventional cleaning techniques, but it can be removed by vigorous scrubbing with a clean cloth.

Mead[7] observed that the well-known tendency of water to form continuous films on only very clean glass makes it possible to monitor substrate cleanliness during the final step in the washing process. On truly clean glass a film of water will remain continuous at thicknesses in the micron range. Consequently, with the slide held vertically as the glass is drying after its final distilled water rinse, interference fringes may be seen in the water film. Continuous regular interference fringes indicate a clean slide. Discontinuities in the fringes indicate particles of dust. The film recoils strongly from traces of oil, which are conspicuously indicated by the fringe pattern.

Another test of cleanliness is to direct a fine spray of distilled water on the surface to be tested. If the surface is clean, the droplets will wet it sufficiently well to fuse into a continuous film. If the surface is oily, the water will remain in the form of individual droplets and give the surface a frosted appearance. This test has been used to measure substrate cleanliness.

Associated with the problems of substrate cleanliness is the general cleanliness of the laboratory environment. The same water-spray test has been used to monitor the rate of contamination of a surface exposed to various environments. It is convenient to use a freshly-cleaved mica surface with this test. Such a surface left exposed in the dessicator in which we store clean parts indicated oil contamination over a 24 hour period. Consequently, we now clean substrates immediately prior to use rather than risking contamination by cleaning and storing them. Also as a result of this test, we replaced the asbestos-board shelves supplied with the dessicator with stainless steel shelves. A subsequent test of oil pickup rate showed that the mica surface remained clean for 24 hours.

C. Vacuum and Deposition Techniques

As already observed, tunnel cathode quality appears to be intimately associated with the quality of the vacuum in which the vacuum deposition of the aluminum emitter layer is made. This dependence has been noted with the system operating at an ultimate pressure of 1 or 2 x 10^{-8} torr, rising to between 10^{-7} and 10^{-6} torr during the deposition process. A primary objective of our thin film work is to make the metal depositions under sufficiently good vacuum conditions that film quality becomes essentially independent of this variable. Consequently, considerable

attention has been devoted to the problem of getting from the vacuum system the best performance of which it is capable.

In discussing film contamination by residual gas we have to this point mentioned only the system pressure. However, it is well known that a rapid deposition rate also helps to produce a relatively uncontaminated film. More specifically, the ratio of deposition rate to system pressure should be kept as high as possible; for this determines the relative rates of arrival of metal and gas atoms at the substrate. Accordingly, we have used deposition rates that are usually higher than 100 angstroms per second.

Also omitted in the above discussion of contamination is the important consideration of the chemical nature of the residual gas. For instance, carbon dioxide would be expected to be more troublesome than an equivalent amount of argon. We are not equipped to identify the gasses present in our vacuum system; however, we have used a mass spectrometer to measure the gasses evolved from the aluminum used for vacuum deposition and find it contains an amount of nitrogen equal to three times the amount present in the same volume of air. Of the remaining gas, hydrogen represents 2.1% of the total amount present, oxygen 1/2%, water vapor 0.06%, carbon dioxide 0.1%, and hydrocarbons of low molecular wright 0.2%. This analysis may not be completely representative of the gas evolved from aluminum during deposition because in the test the gas remained in equilibrium with the aluminum sample whereas during vacuum deposition it is contirually pumped. Also, these results do not represent possible contributions due to outgassing of electrodes and other parts of the system.

The steps taken to improve the vacuum deposition process, both directly by suitable deposition techniques and indirectly by reducing system pressure, are described below.

Choice of Vacuum System: In the course of the internally-sponsored investigation that preceeded the present contract effort, it was established both from our own experience and the experience of others that contamination from diffusion pump oil is not tolerable. With the oil system that we originally used, film adherence problems were severe, usually showing up during the anodizing process if not sooner. Although specially designed traps or an inherently better system could have been used to improve film adherence, these measures were seen only as a means of minimizing the problem, not eliminating it. This reasoning led to the choice of an ion-pumped system.

The tunnel cathodes are being fabricated in an Ultek system using a 90 liter per second getter-ion pump with a twelve inch glass bell jar. Two sorption pumps are used for roughing the system; but, to reduce the gas load on these pumps and thereby improve their efficiency, a water aspirator is used first to pull the system pressure down to one or two tenths of an atmosphere. A six inch valve is placed between the bell jar and the ion pump. The bell jar is equipped with a Viton A gasket. Early in the quarter, the sealing edge of the jar was polished to an optical finish, apparently an essential step in getting a consistently tight seal with this type of gasket. This system has shown an ultimate pressure of 1×10^{-8} torr, rising to 6×10^{-7} torr during vacuum deposition of aluminum.

Vacuum System Procedures: In order to keep the vacuum as clean as possible, jigs and fixtures are made of stainless steel (mostly #304) and OFHC copper (nickel plated in some cases). Provisions have been made for admitting dry nitrogen to the system when it is necessary to let the bell jar up to atmospheric pressure. This step reduces the tendency for more tenacious gasses such as water vapor to adhere to the exposed parts. Masks, substrates, and other parts that must be handled are touched only with clean tweezers or clean nylon gloves and are stored, when necessary, in a clean dessicator cabinet made of stainless steel and glass. Stainless steel screwdrivers (for ease of cleaning) are used for such purposes as fastening evaporation boats in place inside the bell jar.

The vacuum system is wrapped with heating tapes that are connected to a timer circuit so that the system can be automatically baked out every night yet will be cool in the morning. This nightly bake out was started during the early part of the first quarter and has been found to yield much better system pressures during film deposition.

A problem associated with regular bake out is severe sticking of the Viton gasket to the baseplate. During the bake out, the gasket temperature reaches about 70°C. Attempts to obtain information on this problem have revealed only that others do not seem to have this difficulty unless the gasket temperature reached 100°C. Removing the Viton from the system and air baking it at about 130°C is of some value. Several other possible solutions are seen, and this problem will be investigated further. It is not serious, but it is a nuisance in that it wastes time and occasionally results in damage to the sealing surface of the gasket.

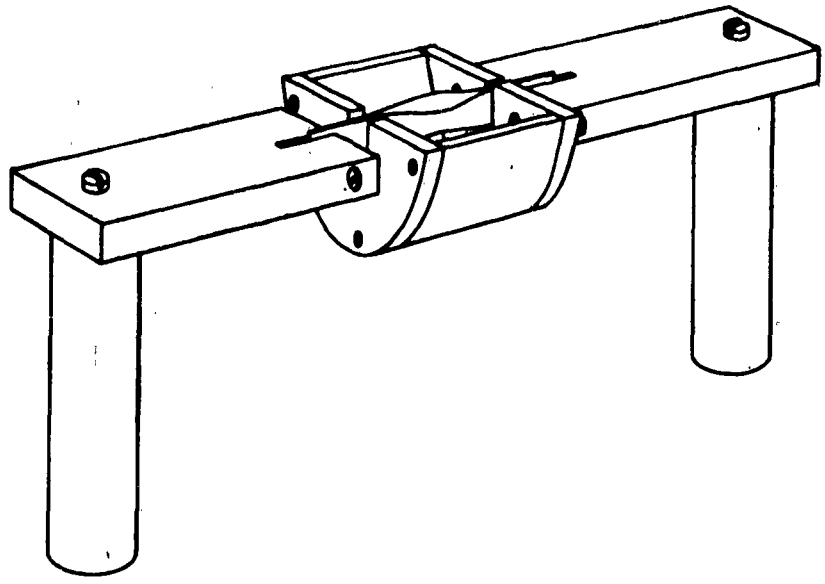
Substrate Heater: To heat the substrate during deposition, a heater was designed and built during this quarter which consists of a stainless steel holder

through which a .010" molybdenum filament was threaded. Quartz tubing was used to insulate the filament from the holder. The heater also serves as the heat source for baking out the bell jar and the fixtures in the upper chamber. Measurements will be made of the substrate temperatures obtained with this heater.

Shutter: A shutter over the metal source permits outgassing the source without exposing the substrate. It also permits establishment of a rapid metal evaporation rate before deposition on the substrate is started, thereby assuring that a more favorable ratio of metal atoms to gas atoms will strike the substrate. A small rotary shutter positioned directly over the source has been in use for about a year. With this type of shutter a sudden increase in system pressure was usually observed when the shutter was rotated away from the source.

A trap-door type of shutter constructed early in this quarter offers several advantages. It is positioned about 1 cm. below the substrate. The aluminum deposited on the larger area of this door before it is opened acts as a getter to pick up much of the gas of the types that tend to adhere to a freshly-deposited aluminum film. The pressure burst noticed with the rotary shutter has disappeared with the use of the new shutter. The trap-door, which is released by the use of a magnet and plunger, opens completely and quickly (this was sometimes a problem with the old shutter). The new shutter cannot be closed. This appears not to be a disadvantage with our present directly heater sources: the thermal inertia is sufficiently small that the evaporation rate drops essentially to zero a fraction of a second after the power is cut. With an indirectly-heated source such as a crucible in a tungsten coil, this type of shutter would probably be unsatisfactory because of the larger time constant of the source.

Electrodes and Vapor Source: The electrode system that was built this quarter was designed to overcome some of the inconveniences and undesirable operating characteristics of earlier sources. The electrodes are nickel-plated OFHC copper because the high thermal conductivity of this material allows the electrodes to run cool, and gas release during the deposition process is consequently reduced. These electrodes take a boat of very simple design shaped like a birch-bark canoe. For convenience in changing boats, the evaporation shield (also made of nickel-plated copper) has been made very small, permitting the clamping screws to be external to this shield. The overall design has been kept as simple as possible to minimize unexposed surfaces that would be slow to outgas. Figure 6 is a sketch of this source.



Electrodes and Heater For Vacuum Deposition of Metals
Figure 6

The boats are made of .005" tantalum sheet. Although attacked by molten aluminum, this material reacts slowly enough to permit a reasonable amount of outgassing of the aluminum charge and several evaporation cycles. The boat can be heated and cooled rapidly, making possible high evaporation rates, the generation of a minimum of unnecessary heat, and an abrupt termination of the evaporation process.

D. Anodization

The insulating film required for the tunnel cathode units is at present formed by anodization of the aluminum emitter film in a non-solvent electrolyte (5% tartaric acid) to produce a thin film of aluminum oxide. Briefly, anodization may be described as an electrochemical method for increasing the thickness of the

naturally-occurring oxide film on the surface of an active metal. The electrolyte acts as a conducting medium to transmit the applied voltage to the surface of the insulating film and also as a source of oxygen ions. The voltage applied across the insulating film in this process serves as a driving force to move oxygen or metal ions through this film in such a direction as to allow the oxidation reaction and the buildup of the insulating film to continue. The reaction proceeds most rapidly where the voltage gradient in the film is highest, i.e., where the film is thinnest; therefore the method produces an insulating film that is highly uniform in thickness. The film thickness is almost entirely dependent on the anodizing voltage.

The emitter layers are anodized at a constant current of 100μa per strip (about 0.6 ma. per sq. cm.) until the desired voltage is reached. This voltage is then held constant until the current drops to approximately 10μa. The effect of variations in this anodizing schedule on the electrical performance of the thin film units is of interest, but a systematic investigation of this variable will be conducted when other factors affecting the insulating film quality are more nearly optimized.

After anodization, the films are rinsed in distilled water to remove any residue from the anodizing solution. Because of some indications that this rinse might not be thorough enough during this quarter, a short series of tests was run in which other processes were tried. These experiments failed to reveal any procedure that should supercede our present one. Again, it is felt that a similar series of tests should be repeated when other variables are such as to yield consistently good electrical results on the thin film test units.

The procedures used were as follows:

1. A control slide was given a rinse in flowing distilled water immediately after removal from the anodizing bath.
2. A second slide was given the same rinse as the control. It was then immersed in boiling distilled water for five minutes. The water was agitated during this time. A reverse current (the direction of the applied voltage was opposite to that normally applied during the anodizing process) of 100 micro-amperes was drawn through the insulating film (film area is about 1 cm^2 per slide).
3. The third slide was boiled in agitated distilled water for 10 minutes.
4. The fourth slide was boiled in agitated distilled water for five minutes.

The electrical test results were as follows:

1. Film current started at 4.5 to 5 volts on the control lot. Most of the units failed by short circuiting at 10 ma (1 amp. per sq. cm.) on the 60 cycle sweep test.
2. Most of those units were shorted initially. Those that were not, started conducting at about 2 volts and shorted at 5 ma. These units also showed physical evidence of damage during the post-anodization treatment. Many holes appeared in the metal film.
3. The third set of units shorted at about 10 ma, and most started to draw current at 2 to 2.5 volts.
4. The last slide is the only one that appeared to be better than the central lot. The test units on this slide burned out at about the same current, 10 ma, but sustained this current for a considerable time (30 seconds on the average) before burning out. One unit sustained 20 ma for 10 seconds. Part of this improvement may have resulted from the reduction in heating associated with the lower tunneling voltage - 3.5 volts.

E. Results Obtained

At present our primary criterion for film quality is the film current that can be supported before breakdown of the test unit occurs. Tests that we made before the beginning of the contract period had demonstrated that with films of good quality current densities of up to 20 amperes per square centimeter were repeatably obtainable over areas one millimeter square using a rectified 60 cycle sweep voltage. Until the end of this quarter, the units produced during this quarter failed to approach this standard. The amount of experimental data is therefore small, because the details of the electrical performance of these films were considered much less important than identifying and correcting the factors limiting this electrical performance.

During the last week of this quarter, the experimental results showed that a pronounced improvement in the insulating films had been obtained. The improved units showed a substantial film current in 75 out of 80 units. The maximum current obtained at room temperature was 70 ma (7 amperes per sq. cm.) with 60 cycle sweep applied. Under liquid nitrogen, the maximum current was 110 ma. Although higher current densities have been achieved in much earlier experiments, this is considered excellent performance in view of the thinness of the accelerator layers and their consequent susceptibility to burnout by thermal dissipation. A second lot of units processed later in the week had similar electrical characteristics.

The variables that have been introduced either in the preparation of these specific samples or a short time earlier are:

1. Vacuum deposition of aluminum under better vacuum conditions.
2. Use of a gold accelerator instead of aluminum.
3. Use of a substrate heater to hold the microscope slides at about 100°C during deposition of aluminum.
4. Anodization at currents of about 25% of the normally used value (this variable was introduced unintentionally).

During the next quarter, it is planned to change these variables more systematically in an attempt to identify their relative importance. More detailed testing of these units is also planned.

Measurements of tunneling current made at liquid nitrogen temperature show two interesting properties: Higher currents can be drawn at the lower temperatures, suggesting that heating due to power dissipation within the units is one of the factors contributing to burnout. Also, the shape of the voltage-current characteristic changes only slightly with the change from room temperature to 77°K, indicating that for our test units the current flowing through the insulator is probably due primarily to tunneling rather than to some other phenomenon such as Schottkey emission. More detailed data to determine the validity of these two conclusions is desirable and will be obtained.

REFERENCES

1. C. A. Mead, The Tunnel-Emission Amplifier, Proc. IRE, vol. 48, pp. 359-361, March, 1960.

2. C. A. Mead, Operation of Tunnel-Emission Devices, Jour, Appl. Phys., vol. 32, pp. 646-652, April, 1961.

3. P. R. Emtage and W. Tantraporn, Schottky Emission Through Thin Insulating Films, Phys. Rev. Letters, vol. 8, p. 267, April 1, 1962.

4. C. A. Mead, Pulse Characteristic Display for Tunnel Emission Devices, Rev. Sci. Iustr., vol. 33, pp. 376-377, March, 1962.

5. J. S. Lemke, Effect of Substrate Cleanliness on Permalloy Thin Films, Jour. Appl. Phys., vol. 33, pp. 1097-1099, March (Supplement), 1962.

6. J. W. Swaine, Jr. and R. C. Plumb, Specific Surface Area of Evaporated Aluminum, Jour. Appl. Phys., vol. 33, pp. 2378-2382, July, 1962

7. C. A. Mead, private communication.

DISTRIBUTION LIST

Contract DA-49-186-ORD-1053	No. of Copies
National Aeronautics and Space Administration	
Washington 25, D. C.	
Code FC/A. M. Andrus	1
Code RET	3
Code RP/W. C. Scott	1
Code RTR/T. T. Neill	1
Code RV/J. W. Keller	1
Code MSA/M. J. Krasmian	1
National Aeronautics and Space Administration	
Goddard Space Flight Center	
Greenbelt, Maryland	
J. Purcell	1
L. Winkler	1
J. C. Lyons	1
M. Maxwell	1
R. Van Allen	1
National Aeronautics and Space Administration	
Langley Research Center	
Langley Air Force Base, Virginia	
J. Stitt	1
C. Husson	1
National Aeronautics and Space Administration	
George C. Marshall Space Flight Center	
Huntsville, Alabama	
D. L. Anderson	1
J. Kessel	1
H. Brown	1
T. Keeffe	1
National Aeronautics and Space Administration	
Manned Spacecraft Center	
P. O. Box 1537	
Houston 1, Texas	
Attn: Instrumentation and Electronic Systems Division	
R. Sawyer	1
D. M. Hickman	1
Jet Propulsion Laboratory	
4800 Oak Grove Drive	
Pasadena 3, California	
F. Goddard	1
J. Konkel	1
J. D. Allen	1

	No. of Copies
National Aeronautics and Space Administration Lewis Research Center 21000 Brookpark Road Cleveland 35, Ohio	1
National Aeronautics and Space Administration Ames Research Center Moffett Field, California	1
National Aeronautics and Space Administration Flight Research Center P. O. Box 273 Edwards, California T. W. Eisenman	1
Department of the Navy Bureau of Naval Weapons Washington 25, D. C. Attn: B. Weiner, Code RAAV-110	1
Department of Defense Director of Defense Research and Engineering Washington 25, D. C. Attn: J. Grodsky	1
Commanding Officer Harry Diamond Laboratories Washington 25, D. C.	
Attn: Technical Director	1
Attn: Chief, Components Laboratory (900)	1
Attn: Chief, Microminiaturization Branch (920)	4
Attn: Chief, Tube Branch (930)	1
Attn: Chief, Materials Branch (910)	1
Attn: Library	1
Commanding General U. S. Army Material Command Washington 25, D. C. Attn: Dr. R. Siu	1
Advisory Group on Electron Devices 346 Broadway New York 13, New York	1
Commander Armed Services Technical Information Agency Arlington Hall Station Arlington, Virginia	1

	No. of Copies
Chief, Bureau of Ships Department of the Navy Washington 25, D. C. Attn: A. H. Young, Code 681A1A	1
Commanding Officer U. S. Army Electronics Research and Development Labs Ft. Monmouth, New Jersey	
Attn: SandM Br., Solid State and Freq. Cont. Div.(Philip Newman)	1
Attn: Solid State Division (H. Jacobs)	1
Attn: Technical Information Division	1
Commander, ASD Wright-Patterson Air Force Base, Ohio Attn: N. DiGlacomo, ASRNE	1
Massachusetts Institute of Technology Research Laboratory of Electronics Cambridge 39, Massachusetts Attn: Librarian	1
Philco Corporation Blue Bell, Pennsylvania Attn: J. Spratt	1
General Electric Company Schenectady, New York Attn: Dr. R. N. Hall	1
General Electric Company Electronics Laboratory Syracuse, New York Attn: Dr. W. Tantraporn	1
Semiconductor Device Laboratory Bell Telephone Laboratories Murray Hill, New Jersey Attn: J. M. Early	1
University of Michigan Department of Electrical Engineering Ann Arbor, Michigan Attn: Dr. W. G. Dow	1
C.B.S. Laboratories 227 High Ridge Road Stamford, Conn. Attn: Dr. Wolfgang Gaertner	1

	No. of Copies
Radio Corporation of America Princeton, N. J. Attn: Dr. W. M. Webster	1
California Institute of Technology Pasadena, California Attn: Dr. C. A. Mead	1
Stanford University Stanford, California Attn: Dr. J. L. Moll	1
Stanford Research Institute Menlo Park, California Attn: D. V. Geppert	1
Electro-Optical Systems, Inc. Pasadena, California Attn: Mr. I. Weiman	1
Raytheon Research Division Waltham, Massachusetts Attn: Dr. J. Lavine	1
Sylvania Electric Products Bayside, Long Island, New York Attn: Mr. Julius Cohn	1
Melpar, Inc. 3000 Arlington Blvd. Falls Church, Va. Attn: Mr. W. T. Layton	1